Professor Andrew Watkinson
Centre of Ecology, Evolution and Conservation, University of East Anglia

GM crops may be an unmitigated disaster for biodiversity in the countryside, so some say who are against the technology. Others argue that GM technology will enhance biodiversity in the countryside. How do we know what impact GM technology will actually have on biodiversity? The farm scale evaluations that we have heard about will help in assessing the impact of GM crops on biodiversity, but they are only going to provide a partial answer to some of the questions we are asking. They are with a limited number of crops, they are with a limited number of genetic constructs and they can only relate to a restricted range of organisms. For example, they won't be able to tell us about birds that forage on a much wider scale than the experiments that have been carried out.

What I want to do with you this morning is share an exploration I have basically made in looking at how we can predict biodiversity responses to GM crops. In this talk as a starting point, as Rosie and Phil have both pointed out, the GM debate has to be seen within the context of what John Krebs referred to as the second silent spring, where we have seen intensification in agriculture lead to a decline in biodiversity. This means that many people are extremely concerned, especially in the UK, at the levels of biodiversity that we currently have.

In trying to predict the impact that GM crops may have what I will first do is quantify the response of birds to changes in their food supply, then we will look at how modelling the response of weeds to the introduction of GM crops can be carried out, and then look at how we can predict the response for bird species. Finally, I will end by saying a few words about the need for integrating modelling experiments and monitoring if we are to make progress on this subject.
Rosie has already shown you facts from the Common Bird Census data collected by the British Trust for Ornithology, that birds have responded to an intensification of agriculture. Here we see data on four species, the Skylark, the Tree Sparrow, the Corn Bunting and the Linnet. If we just concentrate on the Skylark we see that their numbers have declined from 1966 through to the end of the last century. The other species show exactly the same pattern and there are large numbers of farmland birds which show exactly the same pattern. The reasons for this decline, as we have already been shown, are complex. There has been an increase in autumn sown cereals. There has been a loss or simplification of rotations. There has been an increase in pesticides. As Rosie has shown there has been increased grazing pressure and intensified grass production. That particularly relates to the south west of Britain, for example.

The effects of these different management factors have been numerous, and their consequences are numerous. One of the most important effects is likely to be the decrease of winter stubbles that have resulted from the increase in autumn sown cereals. This has had an impact on the food availability for birds and consequently for their survival. We are beginning to understand why birds have declined as a result of changes in agricultural practices over the last 50 years. But we also see changes in weed abundance, and weed abundance clearly has an impact, as many of the birds are feeding on these weeds. If we look, for example, at species richness in different crops in the work of Andreasen in the Journal of Applied Ecology and look at the species richness in a number of crops, spring barley, spring rape, winter rye, winter wheat and in grass leys, what you can see is that in all of these crops the species richness has declined with the intensification of herbicide applications from the period 1967/70 to 1987/89. So in winter rye there were 6.6 species in this particular survey in the initial period and there were 2.8 in the latter period. If we look at the work of Hald, also in the Journal of Applied Ecology, on plant and species density in spring and winter cereals, what we see there is a similar pattern with plant density being lower in winter cereals and species density also being lower in winter cereals. The units of measurement are different, that's why you get different numbers in the two studies.

So, we can see there has been a change in species richness. We can see there has been a change in plant number. This has had an impact, a very large impact, on the number of weed seeds which birds are feeding on. From the beginning of the last century from about 1900 through to 2000 we have seen an order of magnitude decline at least in the number of seeds. So where there were 10,000 seeds per square metre in 1900, in the year 2000 there were probably less than 1000. There has been a very considerable reduction in weed seed number. How do we predict the impact of changing food availability, the decline of seed number, on bird abundance?

Well, I am going to take a specific example and take you through that. This is one for genetically modified, herbicide tolerant sugar beet. Now Phil has already pointed out that herbicide tolerance can be incorporated into a crop through conventional breeding and also through GM technology. That is certainly true but from the point of view of those who are interested in biodiversity, it is GM crops which are potentially going to lead to the widespread adoption of herbicide tolerant crops in the countryside at the moment. GM is the issue, although I fully accept that different technologies can produce the same result, and Phil is quite right to stress the point that we need to look at agriculture in a much broader way than we are present, looking at both conventionally bred crops and GM crops and looking at various aspects of changes in management on biodiversity.

What I will do now is to look at how birds distribute themselves in terms of food availability, what ecologists call the aggregative response, and look at the impact of genetically modified herbicide tolerant crops on weed abundance and then I will try and link the two. How do birds respond to food? Well here is some data for the Skylark. Here you will see weed seed density on the x-axis, ranging from 100 to 10,000, and here you see the number of skylarks that are found feeding in a hectare and there you will see that the birds, very sensibly, go where there is lots of food, and they don't go much where there is very little food. They show an aggregative response and accumulate in areas of high food abundance. This type of aggregative response is well known. Here you can data for the Yellow Hammer showing how it aggregates in areas of high grain density and here you can see data for the hedgehog showing how it aggregates in areas where there are lots of earthworms. Here we see the Brent Goose aggregating on salt marshes where there is a high density of samphire, Salicornia, and here we see Knot aggregating in areas where there are large numbers of bivavles.

So we know how much a bird will use a particular habitat based on how much food is available and we can describe that by simple mathematical models. How do we predict what will happen to weed numbers? Well there are a number of things we need to know here. We need to know how many plants there are in the field. So if you have fat hen, how many plants do we have in our agricultural field? How many seeds do we have in our agricultural field? We can quantify both of those. We need to know seed production of isolated plants, plants not growing with neighbours of the same species. We need to know how crowding amongst the weeds affects seed production. We need to know how interspecific crowding affects seed production. We need to know something about how competition from the crop affects seed output. We need to know about the extent of seed germination and how weather and various other factors are going to affect seed germination. We can quantify that. We need to quantify how many seeds are going to die in the soil.

Sugar beet is grown on a typically five year rotation, and seeds have to survive essentially from one sugar beet crop through to another sugar beet crop, because the plant can be so easily controlled within cereals. And we need to know something about the effectiveness of weed control as farmers actually implement their various technologies, rather than what we see in agricultural field trials. All that information can be put together in a model, which describes how the number of weed plants will change over time and how the number of seeds will change over time.

We are now in a position to construct this type of model for a wide range of different weeds. Obviously the details of that are not something we want to go into here. Models like this allow us to predict the impact of management on weed numbers. Here are a couple of examples relating to weed technology. One of these weeds here is Anisantha sterilis, otherwise known as sterile brome, the other is black grass, a very significant weed of cereals. As you can see if you look at the yellow bars, the sterile brome does very well where there is minimum tillage and where the stubble is unburnt. Where you burn the stubble you decrease the numbers. Plough the fields and if you don't burn the stubble you are left with a few plants, but if you burn the stubble and you plough the fields you get rid of the plants. We can predict that. With black grass you can see that those same changes in management, both are annual grasses, lead to rather different predictions about the actual numbers of plants. You can see that changing from minimum tillage to ploughing doesn't have the same impact on abundance as it does in the case of sterile brome.

What I have tried to do here on this next slide is predict what will happen to the number of fat hen, which you see on the top right there in a GM field if the technology allows better control of the weed. Essentially on the left we see that GM technology produces no better control than conventional technology. We have no difference in control and we have the same abundance in a GM field as in an ordinary field. If, however, GM technology is better at controlling weeds and the evidence indicates that it is, from the figures that I have seen, then we get much better control and we get low abundance of the weed. The different lines relate to differing initial weed abundance.

So essentially, as we increase the effectiveness of control in the GM crop, we see a decline in weed seed number. The extent to which that decline will occur will hopefully be indicated by farm scale evaluations. The initial results would seem to indicate that we are going to be down in this region, we are going to be getting very good control of a number of weeds like fat hen. That is the model if you basically go out and spray every year. If you alter your management and spray according to a threshold, if you only spray if there are more than 5 weeds per metre squared, then you can get some rather different results, but the detail of that needn't bother us here.

So, GM technology has the potential to lead to greater control of weed numbers. Now some would say that you can allow the weeds to grow in the crop for a longer period of time as Rosie indicated before you spray and that is certainly potentially true but here you see a range of weeds. It doesn't matter what they are, the red bar indicates the juvenile period and you can see the time of the onset herbicide control in many conventional systems. If you delay the timing of the weed control you are still going to prevent most plants from setting seed. You may have an impact on insect diversity within the young crop but all the indications are that you will still manage to control the weed seeds that birds are feeding on in farmland during the winter. Tied up with this question of when you spray is also the question of what impact is that going to have on yield.

I was always told in agricultural botany that you always wanted to keep your crop basically weed free because if you didn't that would have an impact on yield. Most experiments that are carried out look at how long you should keep the crop weed free. So if you have no days when there are no weeds you can have a massive impact on yield. If you have 30 days where you keep the crop weed free then yield is going to get up to a fairly respectable level. This relates to the critical period.

That's not the way GM technology is going to be applied. This is data for rice again. Here we see the weeds growing with the crop initially and then we make a decision to go in and spray. Clearly the longer you leave the weed in the crop the more you are going to have an impact on yield. How long is that period, is it 20, 30, 40 days? It's going to depend on the crop. But the extent to which farmers are going to delay spraying is going to depend very much on the yield penalty they might incur.

So it looks from the analysis, that GM technology has the potential to reduce weed seed numbers. Does it matter how the farmers respond to the new technology? Well the analysis that Bill Sutherland, Rob Freckleton, Rob Robinson and I carried out indicated that yes it does. Here is a graph of weed seed density against frequency. This shows that many fields have relatively few seeds, a solid line here. So we have a relatively large number of fields with few seeds, we have got a few fields with a large number of seeds. Now what I have shown from the aggregative response data, how birds respond to seed number, is that the birds are going to go to these fields. These are the important fields for the birds; this is where they are going to get food. They are not going to go to these fields that are well managed and have very few weed seeds. So what happens to those fields in the tail of this distribution is absolutely critical.

If we have a higher uptake of the technology by farms where the weed seed densities are high this is going to lead to a reduction to the farms where there are fields with many seeds. We are going to see far more farms with very few seeds. Farmers with difficult fields who have had problems controlling their weeds, may use the technology to control those weeds and we may lose those fields.

On the other hand, if it's the farmers who are interested in technological development who have good clean fields on the whole, who take up the technology, then they may in fact lead to a situation where we don't alter the fields with many seeds in.

What is the impact of that? Well on this complicated 3D diagram what you see here is that if GM technology is better than the conventional methods of control, we will see a decline in field use by Skylark as we come down this part of the response surface. But it matters which farmers take up the technology. If there is no co-variation between the technology and the take up of the weed infestation, then we are looking for a reduction in this zone. If the farmers who have got well-controlled fields take up the technology, we will see reductions of this order, but if the farmers who have large number of weeds take up the technology we will see large reductions in numbers.

All the indications are that GM technology can potentially lead to us to being round about that black spot on the graph where birds can potentially be affected to a considerable degree. In understanding biodiversity impacts I have taken you through from the GMHT crop through weed number to winter bird food. It indicates that there is the potential for the technology to have an impact on bird numbers. But to complete the picture we need to know how that translates through to survival and bird population size, we need to know how modifying the timing of control and how that may affect weed size will impact on the insects feeding on the crop. We need to know how that will relate to summer bird food, breeding performance and how that will impact on the population.

We need to know how that will impact on yield. We need to know how the volume of herbicide is going to be affected, because that can have an affect on run off, on spray drift, water quality, fresh water and terrestrial biodiversity. The picture is a very complicated one and I have only painted a partial picture for one crop. We need to do the same for a range of other crops, for example salt tolerant crops. We need to follow what are the potential biodiversity implications.

Finally, looking at policy making we have to recognise that ecology is a difficult science, that we need to invest in the research that will allow us to make the predictions about the impact of the new technology on biodiversity. We have got to recognise that experiments are essential to answering ecological questions, and it dismays me to see the way in which the public appears to be opposed to experiments because the alternative is to be left making decisions based on ignorance. We need to accept that predictive models are an essential part of this process, and integrate with the experimental approach. We need to acknowledge the risks and uncertainties in the ecological approach and we need to make the decisions based on a framework of predictive costs and benefits.

But my conclusion is GM crops will have an impact on biodiversity. I have no doubt about that whatsoever. Whether it's a negative one, whether it's a positive one, will depend upon the situation, but an impact it will have. Every change in agricultural technology has had an impact on biodiversity. We need to accept that. We need to understand those impacts and farm management needs to mitigate the potential negative impacts of GM technology on biodiversity. Even if the picture I have painted of the fact that GM crops will lead to decline in seed numbers, which will then impact on bird numbers, is correct, it doesn't mean that we should throw out the technology because we have other methods. Whether it is through set-aside, whether it is through other ways of managing the countryside, where we can provide food through alternative means. We have to research what those best methods are. Finally we need to look at how biodiversity management should respond to changed cropping practices.

Thank you very much.